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(54) Title: AUTOMATIC CHANNEL SWITCHING FOR JAMMING AVOIDANCE IN BURST-MODE PACKET DATA WIRELESS COMMUNICATION NETWORKS

(57) Abstract

In a multinode, wireless packet-hopping network, all nodes operate on a same frequency, by waiting for each other. If the frequency is subject to excessive out-of-network jamming, the building computer transmits a "time-bomb", i.e. an instruction for all nodes to change to a different frequency at a fixed time.

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Automatic channel switching for jamming avoidance in burst-mode packet data wireless communication networks

BACKGROUND OF THE INVENTION

A. Field of the Invention

The invention relates to the field of wireless networks in which a large number of nodes communicate with a central computer. The invention relates more particularly to avoiding jamming in such a system.

B. Related Art

The invention is an improvement upon US Application Ser. No. 08/448,286 filed June 30, 1995 (PHA 21,997), which is incorporated herein by reference. The application relates to packet hopping networks in which messages are communicated wirelessly from a central computer to a network of nodes. The central computer has a weak transmitter and does not have the ability to communicate with all of the nodes. Accordingly, various nodes act as re-transmitters for retransmitting information to the others. Such networks are particularly useful for lighting control in a building.

In that application, jamming was avoided by having a transmitting node slide its transmitting frequency with a relatively slow slide frequency. A receiving node would then slide its receiving frequency relatively quickly, to scan for transmitters. The receiving node would then temporarily freeze its receiving frequency upon crossing the frequency used by the transmitter. The receiver could then receive the message intended for it. Since transmission takes place at different frequencies, chances of being stuck at a frequency which is jammed was unlikely.

I. SUMMARY OF THE INVENTION

The object of the invention is to find an improved way to do jamming avoidance in large wireless networks.

This object is achieved through recognition that for many applications, especially lighting, the central computer only has to communicate with the nodes relatively rarely, for instance a few times a day. Accordingly, the central computer and all of the nodes can use a single channel. The channel need only be switched, albeit for all the nodes

at once, in response to excessive use of the channel frequency by transmitters outside the current network.

A further aspect of the invention is a mechanism for getting all of the nodes to switch together to the new channel. In this aspect, commands are sent out substantially in advance of switching, i.e. via "time bomb". The term "time bomb" will be defined below.

The invention has the advantage of substantially reducing the complexity and cost of the nodes.

II. BRIEF DESCRIPTION OF THE DRAWING

The invention will now be described by way of non-limitative example with reference to the following drawings.

Fig. 1 shows a wireless multinode packet hopping network with a jammed area.

Fig. 2 shows a wireless multinode packet hopping network with a heavily jammed area and a more weakly jammed area.

Figs. 3 a-c show frequencies of transmission and jamming.

Figs. 4a-e show flow charts of the operation of embodiments of the invention.

III. DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Jamming avoidance has historically taken various forms. The most common types fall within the category called spread spectrum. This concept is to spread the frequency spectrum of a transmitted signal in order to avoid a jammed frequency. Three main categories of jamming avoidance are CDMA, frequency hopping and channel hopping, see e.g. A. Bertossi et al., "Code Assignment for Hidden Terminal Interference Avoidance in Multihop Packet Radio Networks", IEEE Trans. on Networking, Vol. 3, NO. 4, 8/95 pp. 441 et seq. All of these jamming avoidance techniques focus on getting pairs of nodes in a network communicating on different channels, be it code channels, frequency channels, or time channels.

The invention uses a single channel of communication. In order to understand why a single channel can be used, it is useful to look at an example of a typical communication. For instance, in a lighting system at the beginning of the day, the central computer can say, in effect, "This is expected to be a sunny day, therefore the lights should

be dim in rooms with east windows in the morning, dim in rooms with west windows in the afternoon, medium brightness in all windowed rooms the rest of the time, and normal brightness in non-windowed rooms." Since the central computer only has to transmit this message once that day, the central computer and the repeater nodes can usually use a single channel to effect the communication. Since the information to be communicated is small, it can be encoded in packets and transmitted as bursts by interspersing the bursts from different transmitters in a time-staggered fashion.

To avoid competition for the channels, the retransmitting nodes implement delays prior to retransmission, to allow opportunities for all nodes to communicate. If any node seeking to communicate finds the channel in use, that node can afford to wait politely for its turn, without interrupting the communication of the others.

Nodes can also wait if they find the single channel in use by transmitters outside the current network. If, however, some nodes discover that statistically there is use of the single channel for too much of the time, then the whole network must change channels. The transmitter from outside the current network can be identified by the nodes using identification codes.

Fig. 1 shows a sample network of the type to which the invention is applied. This is a wireless lighting control network in a building. The central computer 101 issues commands to the nodes a-t. The central computer will generally be referred to herein as "building computer", because the preferred embodiment of the network is a building-wide lighting control network. However, if the network is not a building-wide network or if the network extends over more than one building, the name "central computer" could be more appropriate than "building computer". In any case, whether the device is a "central computer" or a "building computer" is immaterial to the invention, accordingly the terms should be regarded as interchangeable herein.

In the figure, the nodes are shown as interconnected, but the links are wireless. The building computer transmitter is not powerful enough to reach all nodes in the building. Accordingly, various intermediate nodes retransmit any messages from a building computer. Each node has a range of transmission 102, into which it can transmit.

Fig. 2 shows a network similar to that of Fig. 1 into which a jammer J is introduced. The jammer J jams an area 202' strongly and an outer area 202 weakly. Jammer J jams a frequency range around f_j illustrated in Fig. 3a, while the network data appears at a frequency f_1.

Fig. 3c shows the superposition of the network and jamming data. In

Figs. 3a-c the frequencies indicated by arrows are representative of the center of a narrow band (shaded) which can be used for transmission. For ease of description we talk of a single frequency, but actually it is a narrow band of frequencies around the center frequency.

Figs. 4a-e are flowcharts outlining methods for dealing with the jamming. Fig.s 4a-c and 4e occur in the nodes and Fig 4d occurs in the building computer. While the operation of the building computer and nodes are illustrated here in a software embodiment, the functions they perform can also be hardwired.

At the start 401, the node functions in idle state at frequency f1. Transmission is disabled and receive is enabled. Then the node checks whether the received signal strength indicator (RSSI) is high, for instance in the range of -75dBm to the maximum value, at 406. If not, control returns to 401. If the outcome of the test at 406 is positive, control proceeds to 407 where the node tests whether the received signal is a valid packet.

If the signal is a valid packet, control passes to 405 where a response is generated. One possible response is to ignore the packet, in which case, control returns to 401. Otherwise, an acknowledge or repeat signal is enabled at 404, depending on whether the message was destined for the current node or whether it is to be retransmitted. At 403, the response is transmitted. At 402, the transmission is disabled and control returns to 401.

If the signal is not a valid packet, control passes to 408 where it is determined that a jam has been detected. The node then tests at 409 whether the duration of the jam exceeds a threshold, for instance five minutes. The threshold could be expressed in terms of a straight duration or in terms of some other statistical determination of excessive jamming. A statistical determination would require an evaluation of a statistical significance of a period of time jammed when compared with a predetermined interval of time. An example of a statistical determination would be a calculation of what percentage of the time interval is jammed. If a statistical calculation is to performed, the node must be configured or programmed to keep track of the time interval and perform the statistical calculation of how much the node is jammed. If the duration of the jam does not exceed the threshold, control returns to 401. If the duration of the jam does exceed the threshold, then control passes to A, which connects to Fig. 4b.

At 413, the node checks whether the jammer has stopped transmission. If not, the node delays at 414, for instance for 100μs. If the jammer has stopped, transmission is enabled at 415, and a jamming status report is transmitted at 416 on frequency f_1. The jamming status can indicate the duration and level of jamming. The jamming status report could also indicate what channels are free in the vicinity of the current node. Transmission

is disabled at 417 and control returns to B on Fig. 4a.

After B, control returns to 411, where the node tests whether the jamming status report has been transmitted more than 7 times. If not, the node delays at 410 and returns to A. If the jamming status report has been sent more than 7 times, then control returns to 401. All seven times, the packet has the same I.D. to ensure that the receiving nodes treat them in the same fashion.

In the description of the various flowcharts herein, numerical examples are given for values, including of delays, thresholds, numbers of repetitions, lengths of time, and signal levels. All of the numerical values or ranges are suggestions only. The actual numbers or ranges are a matter of design choice. Those of ordinary skill in the art can set these values at any level which works out well in context.

Fig. 4c shows an alternative embodiment to Fig. 4b, though it also incorporates 4b as a subroutine. In the embodiment of Fig. 4c, after A, a jam is detected at 418. Then the signal strength is measured at 419. At 420, the node tests whether the signal strength is medium. If no, i.e. if the signal strength is high, control passes to 413. What constitutes "low", "medium", and "high" here is a matter of design choice, but reasonable ranges could be as defined in the following table.

high	-65 dBm to max
medium	-75 dBm to -65 dBm
low	below -75dBm

If yes, i.e. if the signal strength is medium, control passes to 421, where the node checks whether the duration of the jam is greater than some threshold. If the duration of the jam is greater than the threshold, then transmission is enabled at 424 and the jam status report is transmitted at 423 <u>without waiting</u>. In other words, at this point the node has determined that it is not in the region of strongest jamming and that there is a reasonable chance that the jamming status report is going to be received despite the jamming. Subsequently, transmission is disabled at 422 and control returns to B in Fig. 4a. If the medium strength jamming is not greater than the threshold, then, at 426, control returns to 401.

Fig. 4d illustrates the routine which is performed in the building computer ("BC") relating to jamming.

At 427, the first jamming status report is received. At 428, BC starts a

count of time T_D. At 429, the total duration of previous jam reports, during the current T_D period, is added together, i.e. the sum of non-overlapping durations from various jam reports. If the total duration of the jamming does not exceed a threshold, e.g. 1 hour, at 434, control passes to 433, where it is tested whether T_D exceeds another threshold, e.g. 1 day. If 433 results in a negative determination, BC waits for the next jam report at 431 and control returns to 429 when that report is received. If 433 results in a positive determination, then control passes to 435, where the next jam is also awaited, but control returns to 428 after 435 rather than to 429, because the length of time between jam reports is sufficiently long that there is no cause for concern. In this way, the system tests whether the total duration of jamming over the course of a day is at least one hour.

Upon a positive determination at 434, control passes to 435, where BC selects an available alternate channel and fuse time, e.g. 5 minutes × the number of nodes. Based on the fuse time, BC sets a time-bomb count down timer at 436. At 437, BC transmits the time-bomb command several, e.g. 7, times. The time-bomb command will state the time at which the nodes are to change channels and the frequency to which they are to change. A proposed message format could be

node address	packet I.D.	command ("time bomb")	new frequency	fuse time	check-sum

At 438, BC checks to see if all nodes have responded. If some nodes have not responded after a time T_A, e.g. one quarter of the fuse time, a time bomb abort command is transmitted at 443. At 442, if all nodes have not responded at 442, the time bomb abort command is retransmitted. The abort command could have the following format

node address	packet I.D.	command ("abort time bomb")			check-sum

At 441, BC delays and control returns to element 436.

If not all nodes have responded but T_A has not expired, then control returns to 437, where the time bomb is retransmitted several times.

If all nodes have responded to the time bomb, then BC changes to the new frequency at 439 and waits for the time bomb to fire at 440. At 455, the new communication channel is checked to see if it is functioning adequately. If not, an error message is displayed at 444. The user can then be asked to choose options, such as starting channel switching

again or choosing a channel. If the new channel is functioning properly, then normal operation is resumed at 446.

Fig. 4e is a flow chart for the processing of the time bomb command in the node. At 447 the time bomb command is received. At 448, the node acknowledges the time bomb command. At 449, the node tests whether a time bomb counter is already active. If so, the new time bomb command is ignored at 450. If not, the time bomb counter is set at 451. In this way, two time bombs are prevented from occurring at the same time.

At 452, the node tests whether the time bomb count is complete. If not the node delays at 453, e.g. for 100 μs, and then tests at 454 whether there is a time bomb abort. If there is no abort, control passes to 452. If there is an abort, the node sends an acknowledge to BC and control passes to 457. If the time bomb count is complete at 452, then control passes to 455, where the receive and transmit frequencies are set to the new value specified in the time bomb command and control passes to 457. At 457, the node returns to normal listen mode on the new frequency.

Ordinarily it would be assumed that the building computer would be programmed in a high level language such as C or visual basis. The processors in the nodes would be small microprocessors such as the Motorola HC11, which are best programmed directly in assembly language.

While the systems herein have been described in terms of programmed processors executing software, the same functions can be performed in hardware, such as ASICs.

CLAIMS:

1. A node for use in a wireless multinode network, the node comprising a wireless transceiver arranged to transmit and receive signals from other nodes in the network on a same fixed frequency; and

a processor arranged to

- detect a jammed status;
- provide a jammed status report; and
- process a broadcast command to change to a second frequency after a fixed period of time.

2. The node of claim 1 wherein the jammed status may be low, medium, or high and wherein the processor means transmits the jammed status report when the status is medium or low and delays the jammed status report when the jammed status is high.

3. The node of claim 1 wherein the jammed status report is provided only if the duration of the jamming exceeds a threshold.

4. The node of claim 3 wherein the threshold is calculated as a statistical significance of an amount of time jammed when compared with a predetermined time interval.

5. The node of claim 4 wherein the statistical value is a percentage.

6. A network comprising

a central computer;

a plurality of nodes arranged to communicate wirelessly with each other and to operate on a packet-hopping basis, all of the nodes being arranged to operate on a same single frequency as each other and as the central computer, wherein

each node comprises a respective processor arranged to

- detect a jammed status;
- provide a jammed status report; and
- process a broadcast command to change to a second frequency after a fixed period of time; and

the central computer being arranged to process the jammed status report and issue the

broadcast command at least once in response thereto.

7. The network of claim 6 wherein at least one of nodes is arranged to create the jammed status report if a period of time jammed exceeds a threshold.

8. The network of claim 7 wherein at least one of the nodes is arranged to create the jammed status report after a statistical calculation indicating a significance of an amount of time jammed when compared with a predetermined time interval.

9. The network of claim 6 wherein the central computer is arranged to test, after issuing the broadcast command, for acknowledge signals and to abort the broadcast command in the absence of acknowledge signals.

10. A node for use in a wireless multinode network, the node comprising means for a wirelessly transmitting and receiving signals from other nodes in the network on a same fixed frequency; and means for

- detecting a jammed status;
- providing a jammed status report; and
- processing a broadcast command to change to a second frequency after a fixed period of time.

11. A system comprising a plurality of nodes as claimed in claim 11 and a central node for processing the jammed status report and issuing the broadcast command at least once in response thereto.

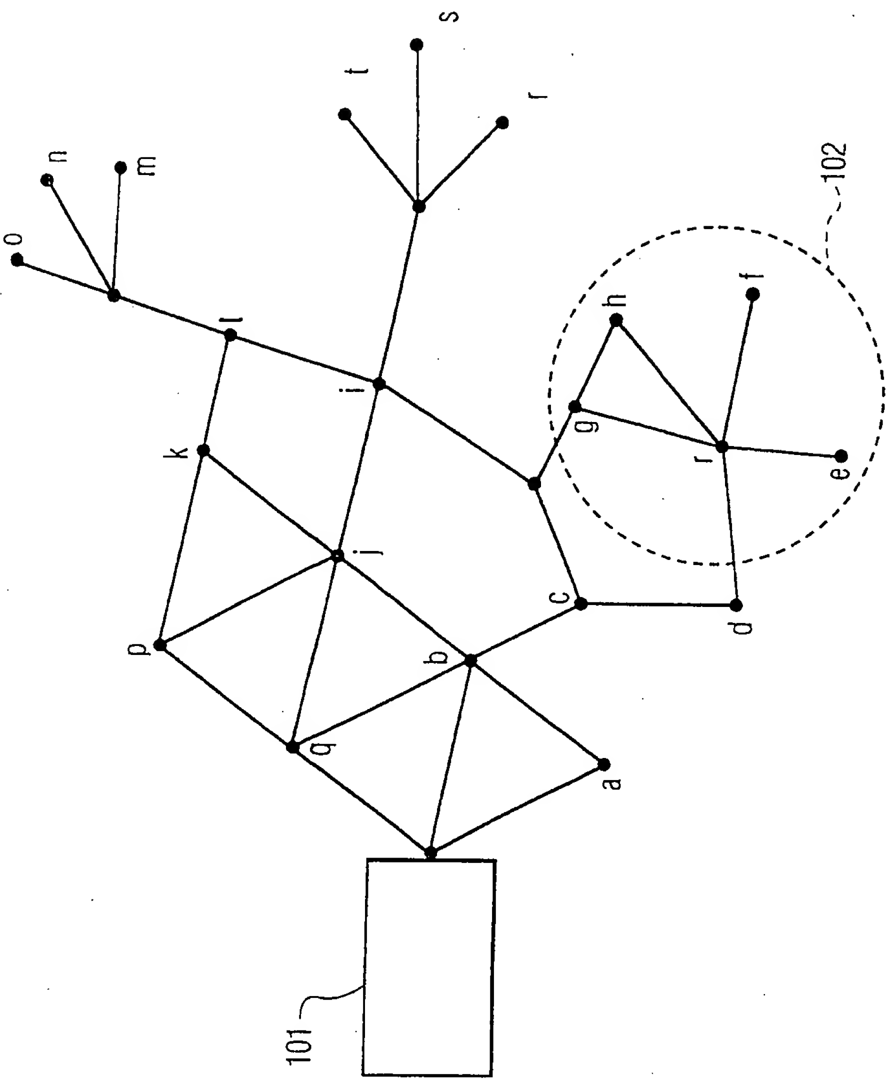

FIG. 1

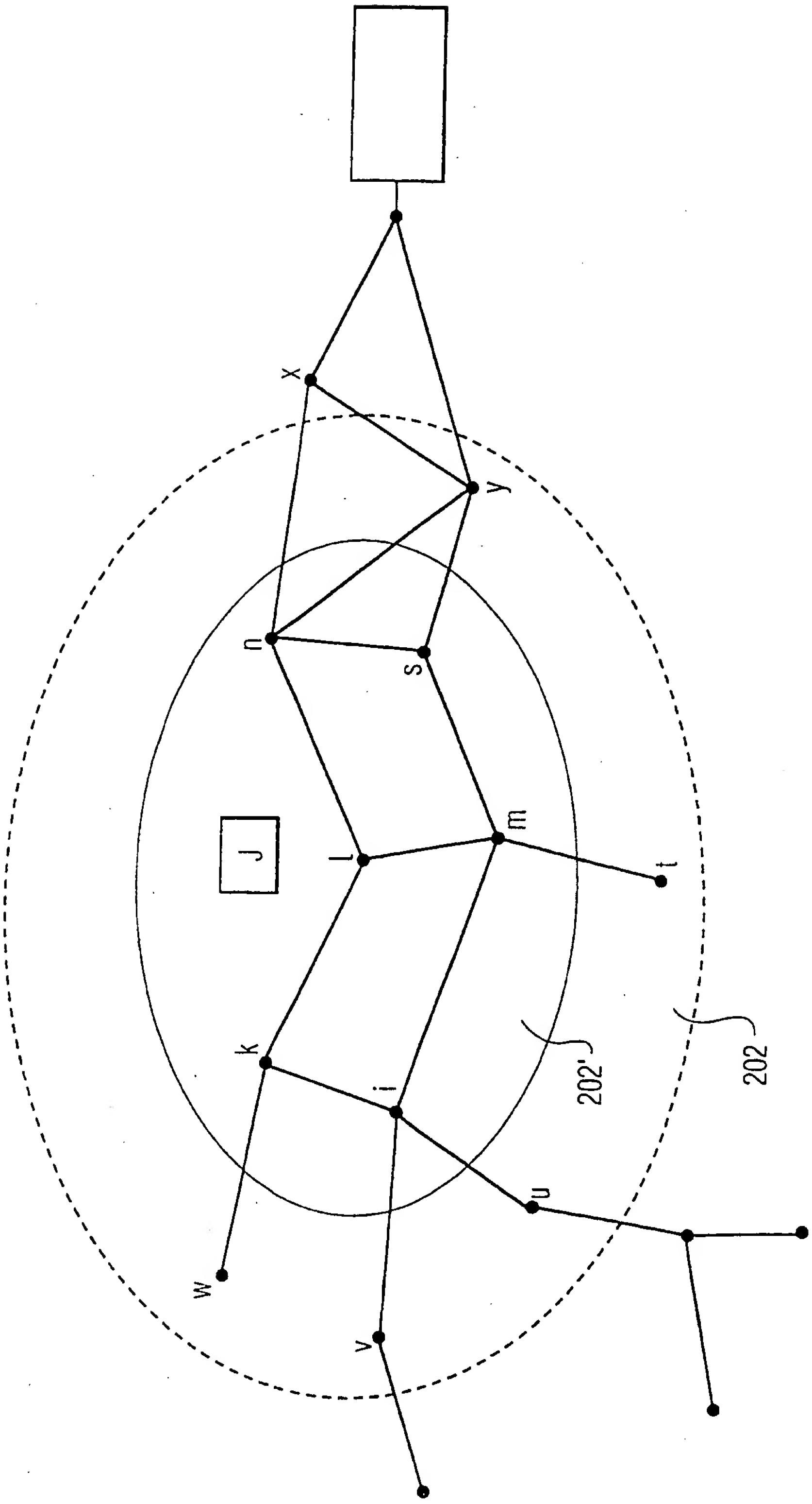

FIG. 2

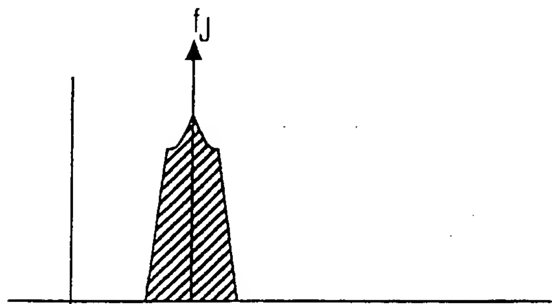

FIG. 3A

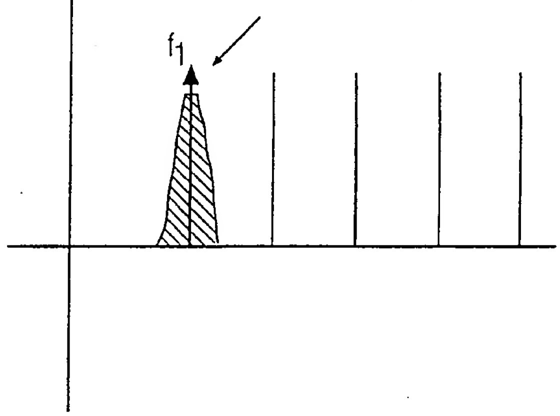

FIG. 3B

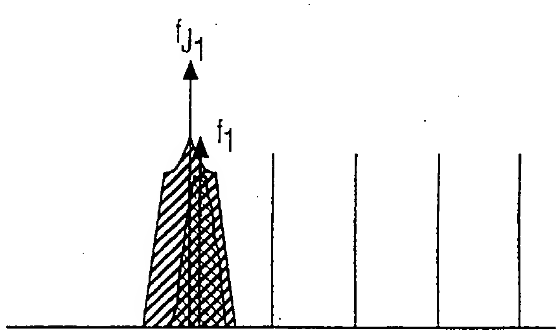

FIG. 3C

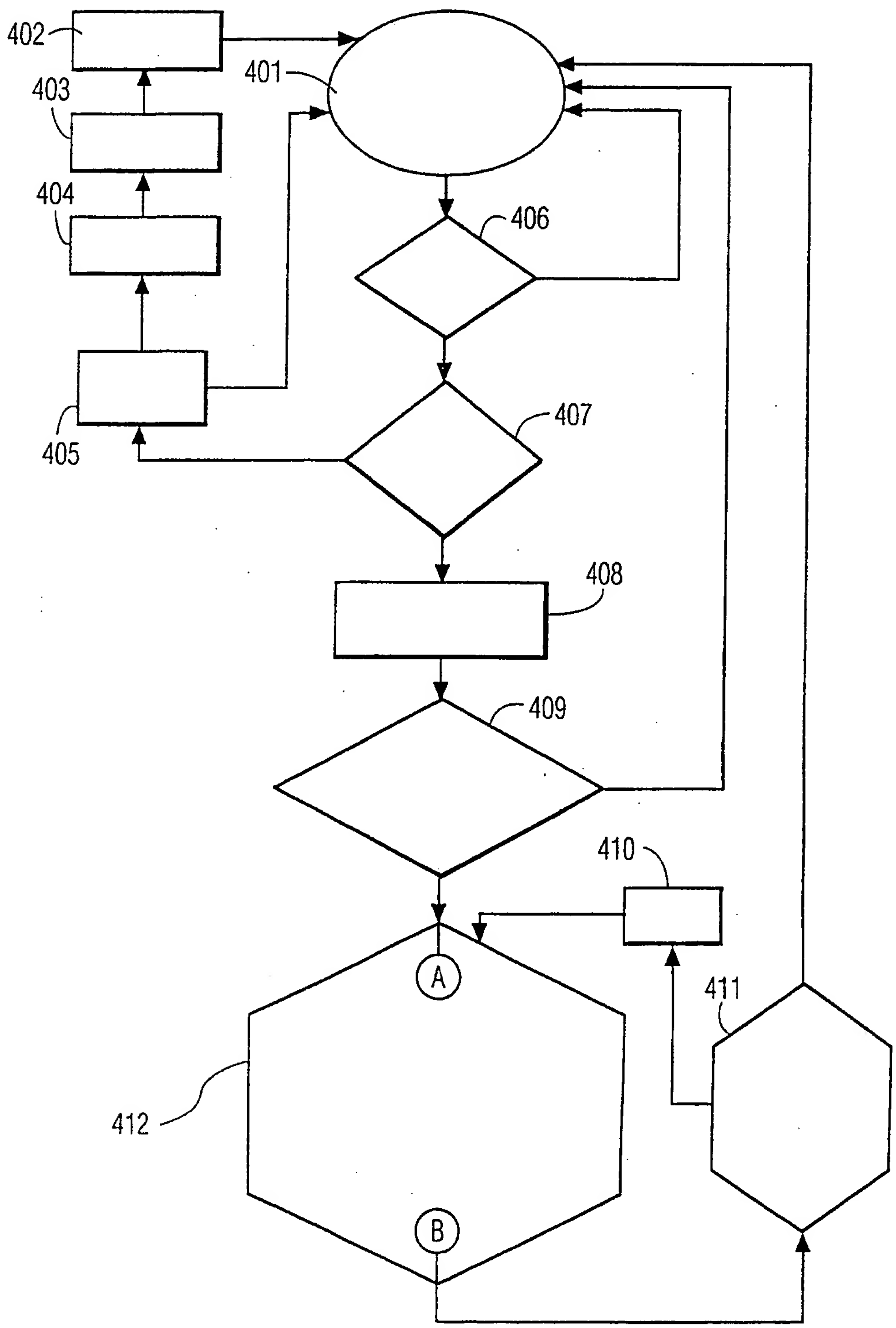

FIG. 4A

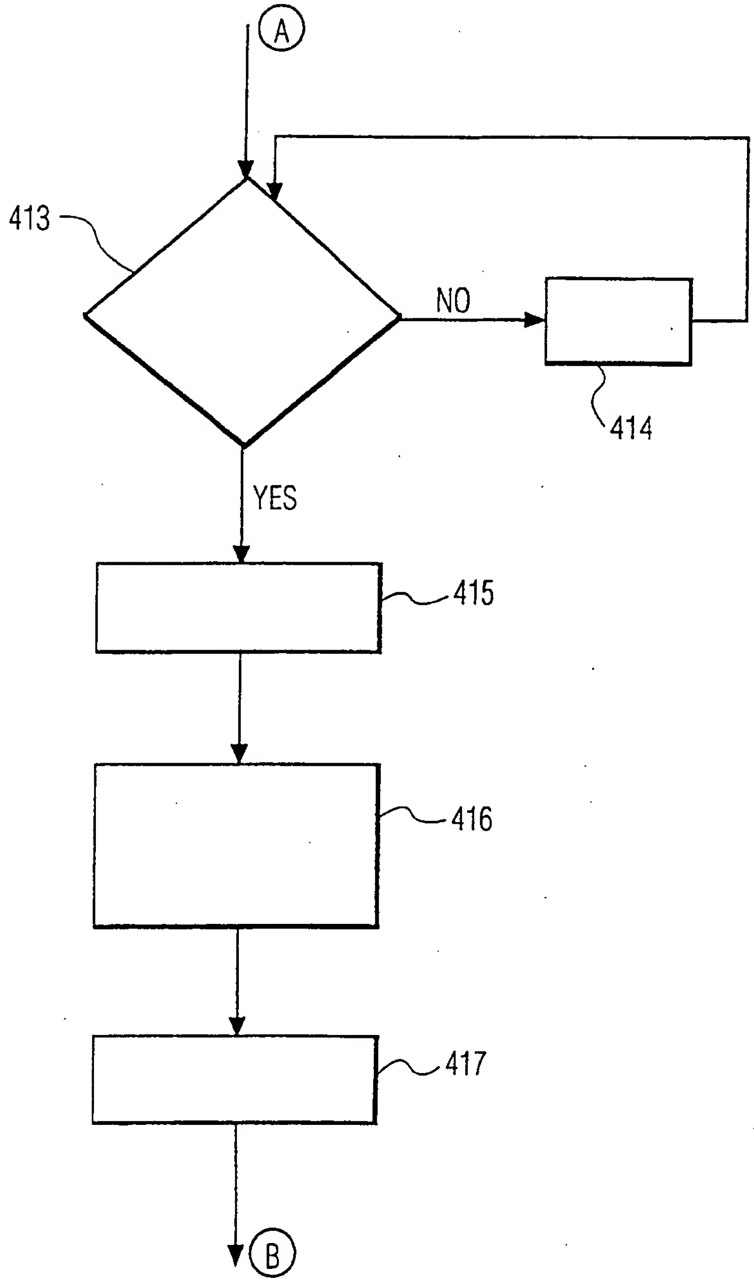

FIG. 4B

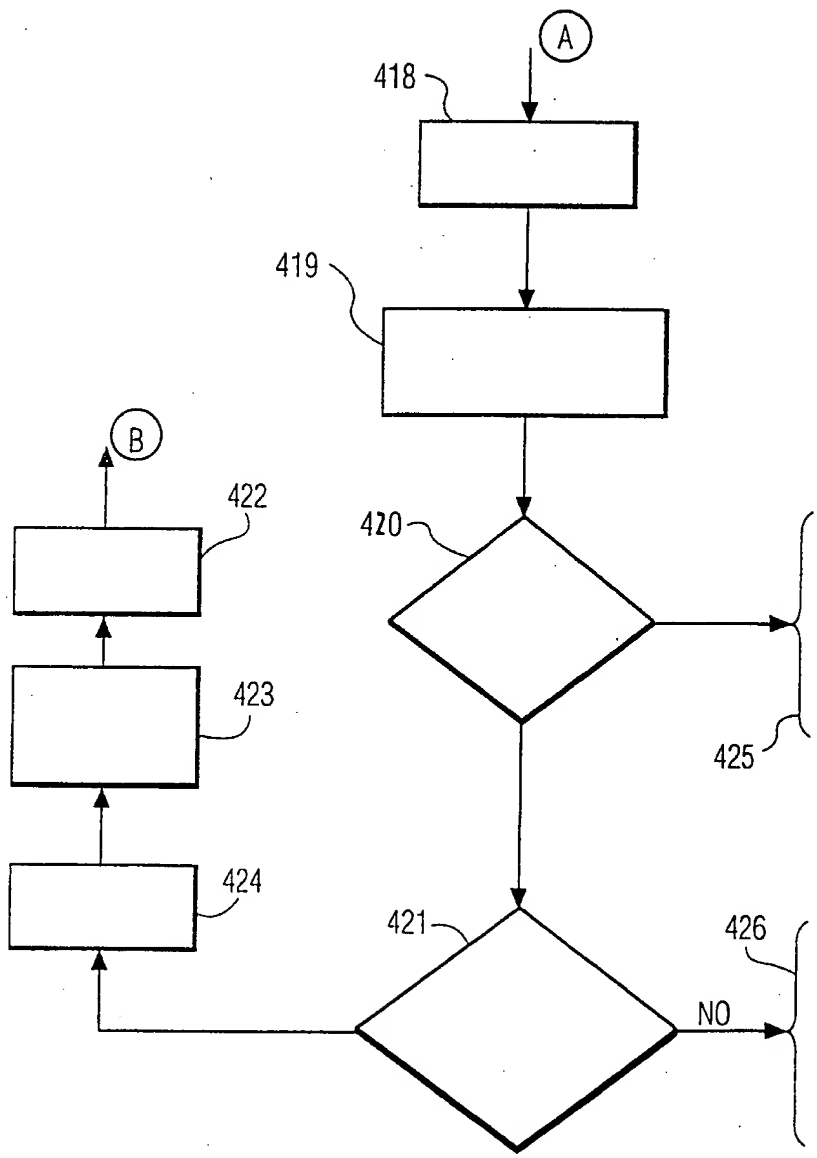

FIG. 4C

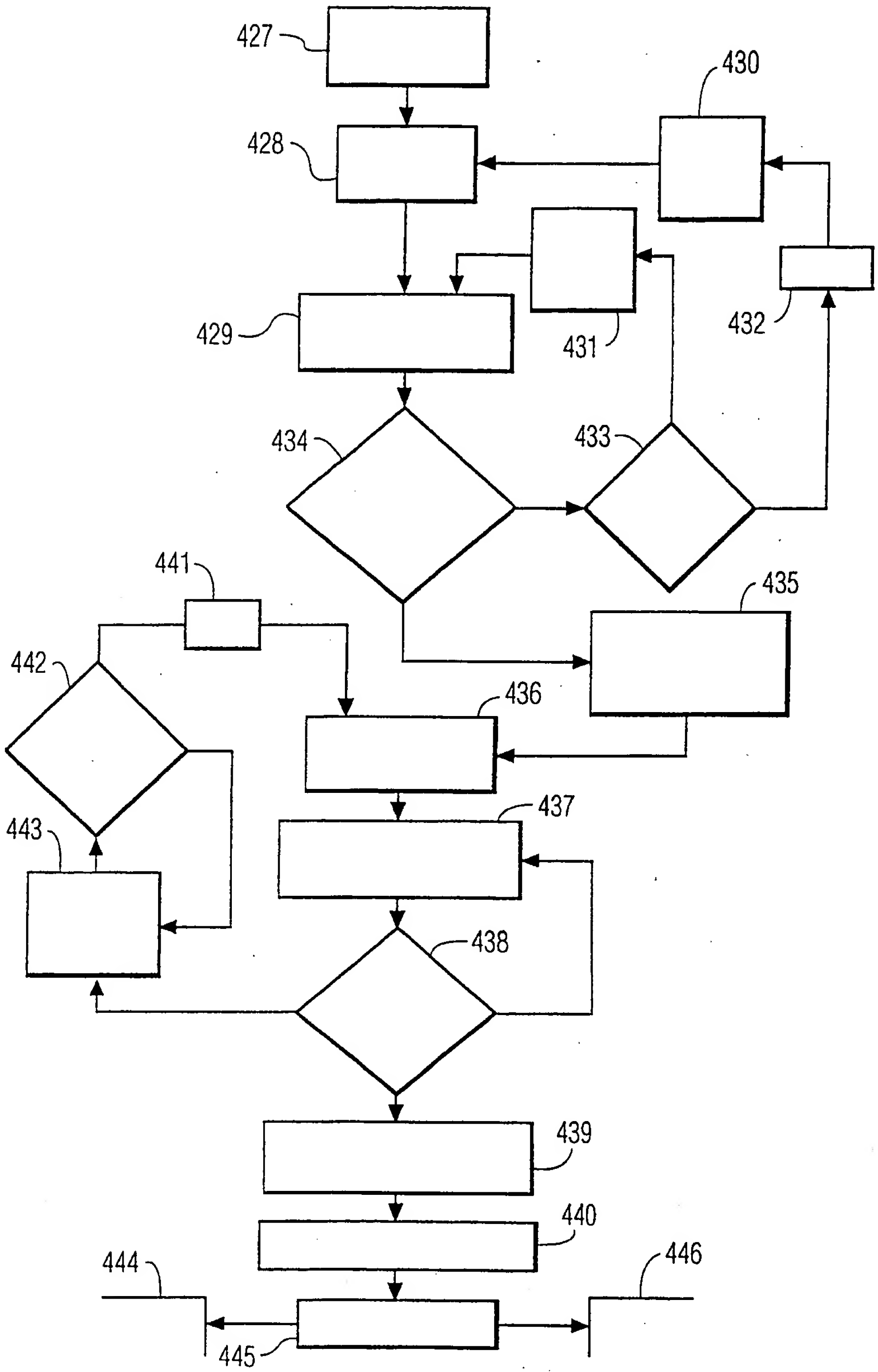
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FIG. 4D

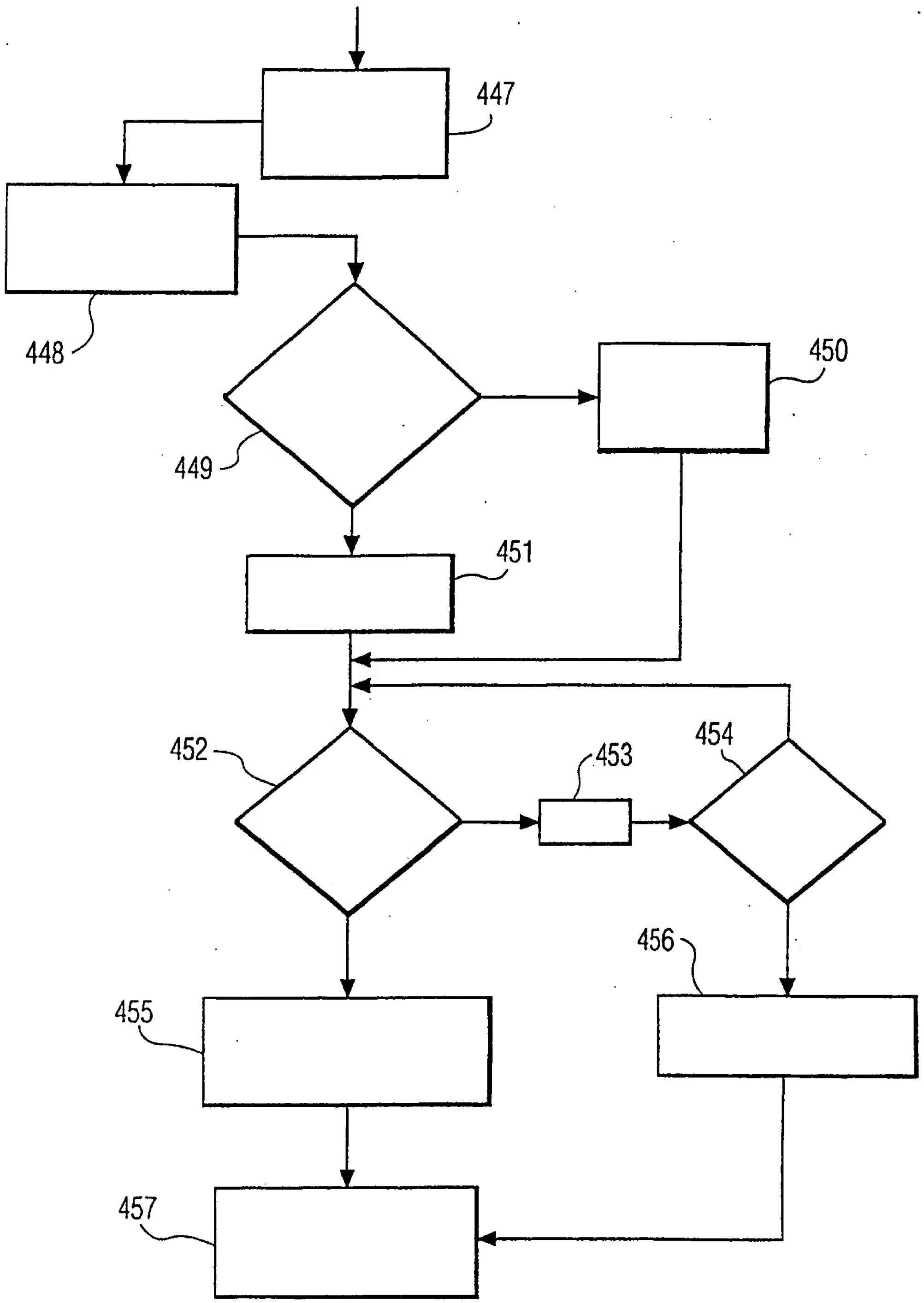

FIG. 4E